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Defense Experimental Program to Stimulate Competitive Research

Equipment Resources for MCM Technology and System Prototyping: Final Report

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1 Introduction

Activation in the early summer of 1994 of the awarded Reactive Ion Etch (RIE) and magnetron sputtering systems, coupled with major corporate donations (AT&T, IBM, Union Carbide) of other critical equipment, has put in place the first microfabrication laboratory at West Virginia University. The System Microfabrication Laboratory is one of three major labs within the Microelectronic Systems Research Center of the Department of Electrical and Computer Engineering, and has been chartered with two important roles. The first is to support prototyping of advanced packaged MCM-based systems and the microfabrication of system-level technologies (e.g. optical interconnections) and devices for insertion in these systems. Already the equipment resources have provided significant leverage in this area. Currently, work is underway in polymeric optical waveguide interconnections through both NSF and ARPA funding. Also a major industry-acadamia collaborative ARPA proposal is now under review in MCM based cryosystems and interconnect in which WVU is at the center providing a microintegrated system design and prototyping role. The awarded equipment resources were also instrumental in helping attract a new faculty member to the Center and Department specializing in design, fabrication and characterization of electronic and optoelectronic devices in novel new material systems.

The second role which has emerged for the System Microfabrication Laboratory is to be a catalyst for interdepartmental collaboration on interdsiciplinary research at West Virginia University enabling faculty teams to effectively compete in a wider range of research than was possible previous to the award of the equipment and activiation of the lab. Over the past four years, aggressive new faculty from both academia and industry have joined the departments of Electrical Engineering, Chemical Engineering, and Physics spanning backgrounds in photonic and microelectronic technologies from materials through devices to advanced packaging. Natural linkage of these faculty is now occuring through development of joint research projects encompassing from materials to prototyping of advanced packaged systems based on the new device structures and packaging these materials enable. The System Microfabrication laboratory, of which the awarded equipment is the foundation, provides the critical fabrication lab resource for completion within WVU of this full research path.

Following a full description of the two equipment systems and their final configurations purchased with this award, the range of current research and pending research proposals for which the awarded equipment is playing a central role will be reviewed.

2 Awarded Equipment Resources

The two pieces of processing equipment purchased under this award were (1) an Oxford Instruments RIE system and (2) a CVC 610 Magnetron Sputtering System. In this section, detailed itemizations of system configurations including all accessories and their cost breakdown are provided for both these systems. Deviations from the accessories originally requested in the original proposal are specifically noted and explained.

2.1 Reactive Ion Etching System

The Oxford Instruments RIE system and all accessories purchased under this award were exactly as specified in the original proposal.

Description	*Cost*
Oxford Instruments PlasmaLab 80 Plus RIE	$79,000
Standard features include:	
240mm RIE Electrode	
300 W 13.56 MHz RF Generator	
Rotary and Turbomolecular Pumps	
One year warranty	
Options:	
Fomblinized O_2 Service Pump	$520
Fomblin Filtration System	$6,920
Oil Mist Filter	$1,972
2 Additional MFC Nontoxic Gas Lines	$6,434
SUBTOTAL:	$94,846
5% University Discount	- $4,742
TOTAL:	$90,104

Delivery and Setup Delivery of the Oxford Instruments RIE system was taken September 29, 1993. The system was activated in late May 1994 following completion of the necessary electrical services and lab modifications for its installation by the university in the System Microfabrication Laboratory.

2.2 Dual Source Sputter/Etch Metallization System

While the basic magnetron sputtering system requested in the original proposal was purchased, an authorized equipment substitution was made for two accessories in order to increase the flexibility of the system as well as further enhance its capabilities for MCM prototyping. A 2" magnetron gun accessory from US Gun, Inc. replaced a full size 8" second electrode in order to enable easily interchangeable use of a variety of economical 2" precious metal targets for process prototyping. The originally requested RF sputter etch accessory was replaced with an ICS-6600 Ion Source allowing more reliable deep via cleaning, consistent with MCM industry moves towards directional ion beam cleaning for high reliability interlevel contacts. The difference in cost of an additional $6,679 was provided through the PI's NSF National Young Investigator Award which currently supports research for which this sputter system plays a central enabling role.

Description	*Cost*
CVC Products Model 610 Sputtering System	$168,000
Standard features include:	
Single 8" DC Magnetron Target Head	
10 kW DC Magnetron Solid State Supply	
24"Diam. Titanium substrate holder for up to six 7" wafers.	
One year warranty	
Options:	
ICS-6600 Ion Source accessory,	$41,679
3 kW substrate heater and controller	$11,500
US Gun 2" DC Magnetron Source	$7,925
TOTAL:	$230,179
Excess funded by NSF:	$ 6,679
Amount funded by AFOSR	$223,500

Delivery and Setup Delivery was taken on the CVC 610 sputtering system on January 6, 1994. The system was activated in late May 1994 when the necessary electrical services and lab modifications for its installation were completed by the university in the System Microfabrication Laboratory.

3 Supported Research: Current and Pending

In this section, research is summarized in which the awarded equipment is or will be playing a central role.

3.1 Polymeric Trans-Module Optical Interconnections

Current Funding:

NSF: National Young Investigator Award (Hornak) highlighting advanced interconnection technologies for MCM-based systems with current emphasis on polymer optical interconnections. Five year term, $312,500 in base and industry matching NSF funds.

DARPA EPSCoR: Polymer optical materials for cointegrated optical interconnections. In collaboration with AT&T Bell Laboratories. Graduate student support for three years, $90,000.

Optical interconnections have great intrinsic potential for achieving high density interconnections across the physical MCM substrate and package boundary. As illustrated by current work exploring the compatibility of GaAs heteroepitaxy with Si CMOS, the greatest hurdle for optical interconnection media within the MCM environment is attainment of full physical and functional compatibility with the dominant electronics packaging and device

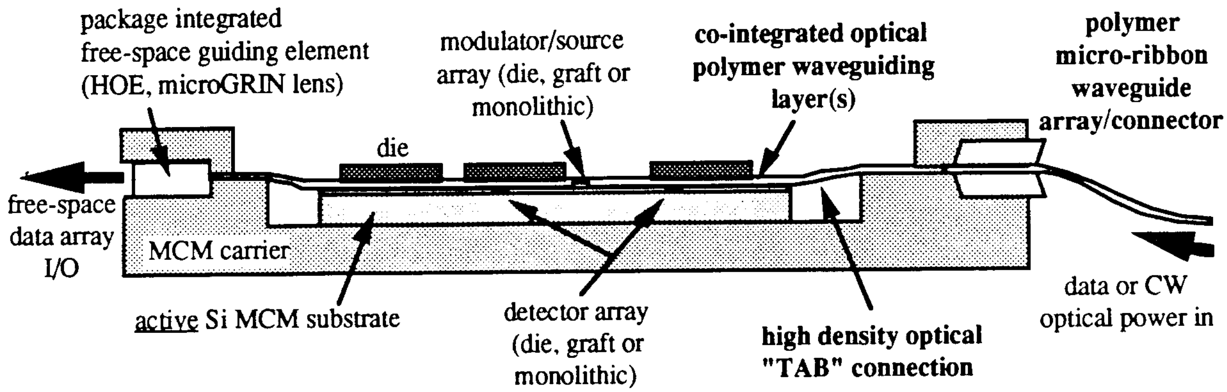

Figure 1: Externally sourced optical interconnection architecture using free-space and/or high density waveguide array flexible microribbon between package boundaries and optical polymer interconnection layers co-integrated with the active MCM substrate within the package.

technologies. Factors making polymeric materials favored for electronic dielectrics within present MCMs (e.g. low temperature processing, engineered TCE matching, thick planarizing films) have also made them a natural choice for optical interconnections, as evidenced by recent work with polymer optical waveguides on idealized substrates (Honeywell, Boeing) and flexible polymer waveguide ribbon cables (DuPont, Honeywell).

Through exploration of the feasibility of an intermodule optical network using polymeric high density waveguide arrays as the basic building blocks, NSF funded research currently underway seeks to determine the limiting interconnection density achievable within multiple substrate MCM systems with a merging of substrate integrated waveguide and ribbon cable polymer waveguide approaches to achieve a "continuous" interconnection fabric. This approach is seen as a natural evolutionary direction in these technologies yielding the highest interconnect density obtainable with planar waveguide approaches. Theoretical and experimental investigations will emphasize those intrinsic and extrinsic factors limiting interconnection density as this polymer waveguiding "fabric" traverses free standing "micro-ribbon" sections and those sections traversing the MCM package and overlying the interconnections and CMOS circuitry of an active MCM substrate. Figure 1 shows an example of where integrated and microcable polymer optical waveguides are merged within an active substrate MCM package environment.

3.1.1 Cointegration Compatible Polymer Material Systems

Seeking polymer material systems suitable for co-integration with passive and active MCM substrates, characterization of promising new optical polymer material systems is underway with industrial affiliates (presently AT&T). Systems of materials include waveguiding layers, planarizing substrate, and superstrate films. Characterization includes bulk, film, and individual waveguide measurements over idealized (featureless, planar) substrates emulating intrinsic micro-ribbon cable or chemomechanically polished substrate performance as well as substrates with controlled underlying process features and full VLSI.

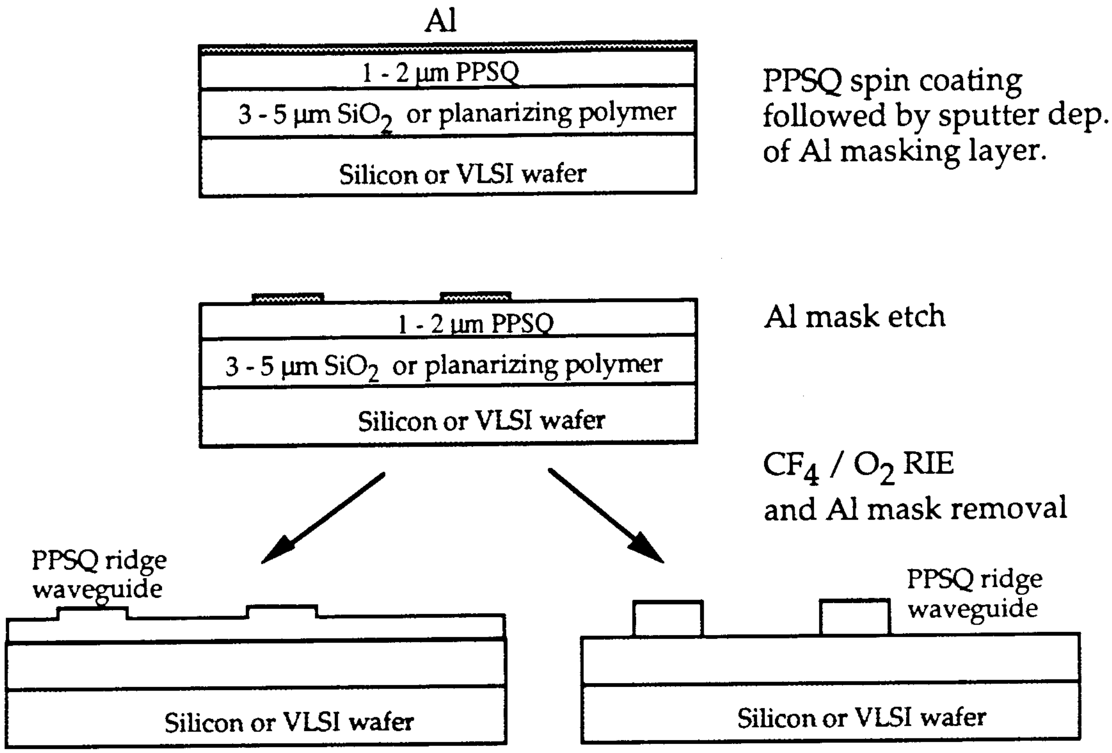

Figure 2: Fabrication process currently under study for PPSQ ridge or rectangular polymeric optical waveguides.

Experimental efforts now focus on the siloxane material polyphenylsilsesquioxane (PPSQ) in collaboration with Weidman at AT&T Bell Laboratories. This high temperature stable polymer exhibits excellent optical clarity and potentially good processibility and is currently under exploration by other investigators as an electronic interconnection dielectric material. The awarded RIE and sputter etch equipment systems are both central to the current work of developing a process for fabrication of the first waveguides in the PPSQ material. As indicated in Figure 2, an Al mask is being used as a mask for a tetraflouromethane/oxygen RIE etch with which the ridge or rectangular waveguides are defined. This process development is currently underway with the first completed two dimensional waveguide samples expected to be available soon for characterization.

3.2 MCM Based Cryosystems and Interconnect

Proposed Funding:

DARPA Focused Research Initiative: *Cryogenic and Optical Environments for High Performance Computing and Communications.* WVU is prime for five subcontractor partners. Total 3 year funding: \$5.2M. Proposal Pending.

This major effort leverages the new MCM prototyping capability enabled by the awarded equipment and teams with four industry partners and another academic institution to demon-

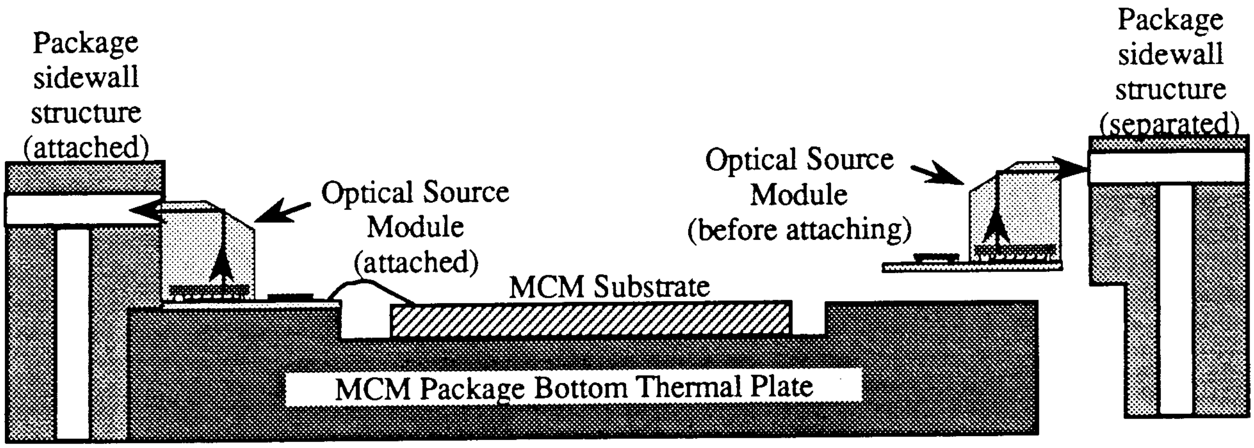

Figure 3: Illustration of the proposed MCM prototype system package with optical I/O using a pre-assembled optical module, optical I/O ports in the MCM package, and a high thermal conductivity connection through the base plate to a cold plate.

strate not only new system-level technologies for standard room temperature electronics but also advantages obtained by lowering the temperature of optoelectronic components, VLSI components, and specialized GaAs and other high-speed electronics. A novel approach is put forward for readily cooled MCM packages including optical I/O ports designed to provide ease of assembly, isolation of precision alignments to preassembled optical elements, and compliance with mainstream conventional MCMs developed for electrical I/O ports. A diagramatic representation of the proposed system demonstration platform is shown in Figure 3. The addition of the optical I/O ports supports significantly improved thermal cooling of ICs to an external cold plate, enabling low cost approaches for liquid cooling of MCM-based electronics. The approach addresses high power dissipation and high pinout in evolving room temperature VLSI electronic systems, however, it also provides ready extension to cryogenic temperatures merely by changing the temperature of the coolant. The work will be performed by a team of established experts in the technologies targeted for introduction in the system demonstrations. The team consists of Westinghouse Electric Corp., Honeywell Technology Center, Optical Concepts, Inc., Hypress Inc., the University of California at Santa Barbara, and West Virginia University.

The MCM prototyping capability of the MSRC System Microfabrication Laboratory will heavily support West Virginia University's central role in this proposed program. The signal processing application which will be targeted for evaluation will have die provided by one of the industry team members and these die will be mounted on an MCM substrate designed and fabricated at WVU. In addition, WVU will share in the responsibility for the design, modeling, and fabrication of the optoelectronic source/receiver module illustrated in Figure 4(a) and will be responsible for the microfabricated passive guiding elements of the sidewall structure illustrated in Figure 4(b). The PIs feel this project is very much indicative of the significantly broadened range of research which the awarded equipment enables.

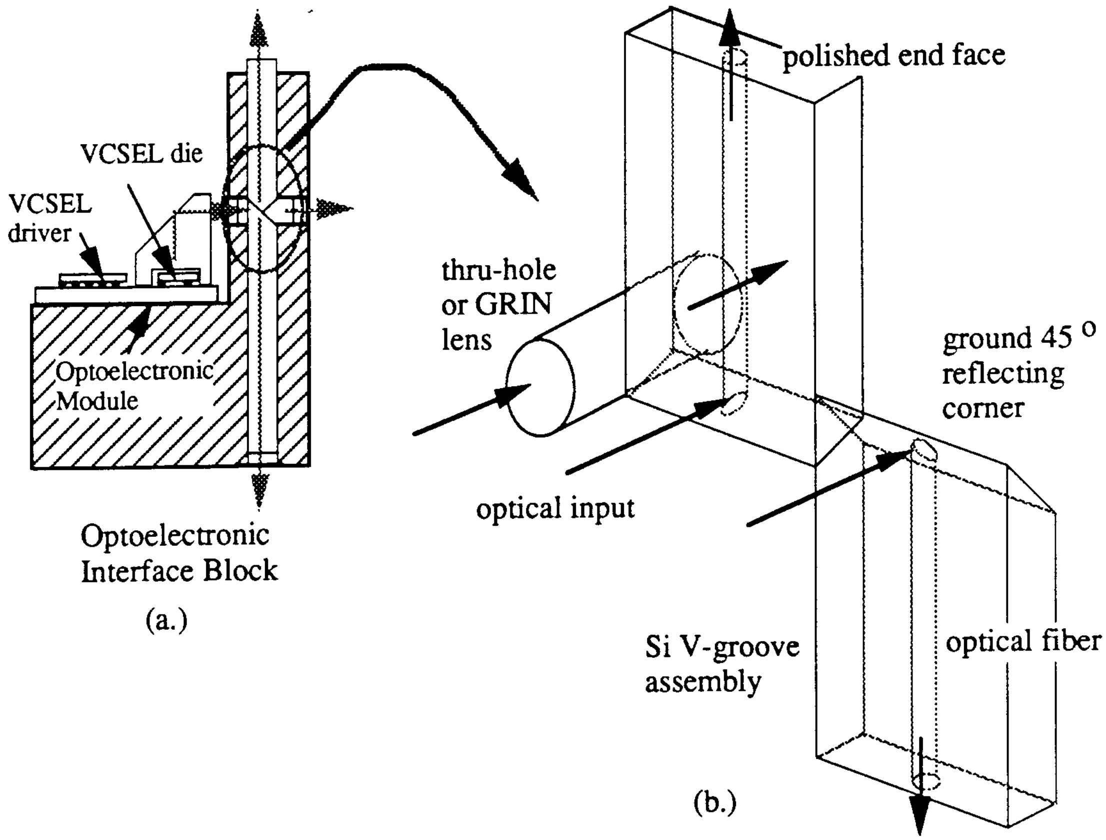

Figure 4: Optoelectronic sidewall assembly indicating microfabricated passive routing elements.

3.3 Nanostructure Research

Planned Funding: NSF Directorate of Materials Research, ARPA/DOD

In August 1994, Dr. B.J. Das, a Purdue graduate with a strong electronic and optoelectronic device background, was sucessfully recruited to the Department of Electrical and Computer Engineering at WVU after three years at the University of Notre Dame. The awarded equipment and the MSRC microfabrication lab resources it helped complete were a strong contributing factor to Das' decision to join WVU. In addition to his nanostructure research detailed below, Das is also a co-PI on the cryosystem and interconnect proposal discussed above and an additional catalyst for joint interdiscipliary proposals bringing together research expertise at WVU through device and system technology applications.

3.3.1 Semiconductor Quantum Dot Arrays for Non-Linear and Electro-Optic Device Applications

Semiconductor quantum dots in the size regime of 2 nm to 10's of nanometers have strong electro-optic and nonlinear optical properties with the potential for novel and ultrafast optical devices. However, it is not possible to fabricate periodic arrays of such quantum dots with the current lithography and etching techniques. Das is using a novel fabrication technique utilizing material growth on a preformed template to produce arrays of quantum dots of such small dimensions. The template, fabricated by electrochemical anodization of

aluminum, contains the periodic array of pores in which the quantum dot material is synthesized. To achieve VLSI compatibility as well as future optoelectronic integration on silicon, the template is created on silicon substrates by anodizing aluminum deposited on silicon. Investigations are currently under way to ascertain the effects of aluminum deposition conditions on the quality of the template as well as on the synthesis of the quantum dots. Previous efforts by Das at Notre Dame focused upon evaporated aluminum films. The awarded CVC 610 magnetron sputtering system will enable an expansion of these studies to include the effect of sputter deposition on template formation in aluminum thin films.

3.3.2 Properties and Applications of Porous Silicon

Porous silicon is an intriguing material with potential for silicon based optoelectronic integrated circuits. Porous silicon is formed by electrochemical anodization of silicon in a hydrofluoric acid solution. For successful anodization, it is essential to have a good ohmic contact which is typically achieved by deposition of aluminum followed by annealing. The porous silicon research at WVU includes investigation of the light emission mechanism, implementation of light emitting diodes and fabrication of electro-optic devices. One experiment of particular importance is the demonstration of quantum confined Stark effect in this material. Aluminum electrodes are deposited on top of the porous silicon layer and the optical properties of the material are monitored as a function of the applied external voltage. The results unambiguously demonstrate quantum confinement to be the light emission mechanism in this material as well as show that porous silicon is an electro-optic material. The awarded CVC 610 sputtering system, in conjunction with the other facilities of the MSRC System Microfabrication Laboratory, provide the critical resources for Das' continuation and expansion of this work at WVU.

3.4 Device Structures for GaN Materials Growth and Process Evaluation

Planned Funding: NSF, ARPA/DOD

The newly opened System Microfabrication Laboratory at WVU has enabled expanded joint research not only with other academic institutions and companies such as in the projects summarized above, but also with other departments within WVU. The Departments of Physics, Chemistry, and Chemical Engineering each individually have active funded research in GaN MBE material growth, in situ growth kinetics measurement, plasma chemistry, and electro-optic materials characterization. However, apart from collaborations across these departments in support of these basic materials studies, meaningful collaboration with electrical and computer engineering allowing evolution and expansion of these projects to include realization of device structures has not been possible due to the absence of basic microfabrication capabilities at WVU.

Since activation of the System Microfabrication Laboratory, strong coupling of efforts in these departments have rapidly developed, driven by the device fabrication capabilities of this lab. Present joint efforts center around a proposal exploring fabrication of device structures in the GaN material system both for the sake of study of the devices themselves as well

as for evaluation of the GaN material growth techniques and fabrication processes to be used. Optoelectronic devices will be emphasized including detector and emitter structures suitable for evaluating both bulk material quality and device fabrication induced defects (e.g. etching induced surface recombination) This proposal will leverage both the present DEPSCoR equipment award for device fabrication and a three year DEPSCoR research award to the physics department announced during the summer of 1994 supporting GaN MBE growth. Prior to the availability of quality GaN materials from WVU, a collaboration has been established with another GaN grower to provide quality material in order to immediately begin work on device process development.

The extensive in-situ plasma process evaluation capabilities of the Chemical Engineering department developed through its silicon carbide and diamond thin film funded research will be used for development of GaN etching techniques which will be transfered to the Oxford RIE system for use in actual device fabrication. Strong emphasis will be given to development of noncorrosive etch chemistries, however, chlorine chemistries which have been demonstrated by other investigators will also be considered. The Oxford Instruments RIE system purchased under this award provides an excellent foundation for application of these etching studies to fabrication of optoelectronic device structures. The PlasmaLab Model 80 Plus is already prepared for corrosive service with the exception of a purged glove box and any additional needed mass flow controllers. The proposal under preparation will also seek support for purchase of an ECR head for the PlasmaLab system. The ECR head will further broaden the range of application of the awarded RIE system to include this and other advanced device work.

During device fabrication process development, a suitable ohmic contact metallization will also be established. If simple contacts metallurgies prove viable (e.g. using only one or two metals), the capabilities of the awarded CVC 610 magnetron sputtering system will be used. If additional sputter sources are required for specialized metal deposition without breaking vacuum, a second US GUN 2" DC magnetron sputter head can readily be added to the system.

4 Summary

The awarded equipment, while only active for less than half a year, has already been a catalyst for expansion of materials, device, and system-level technologies research at West Virginia University. The Oxford Instruments RIE and CVC magnetron sputter systems completed the basic resources for the MSRC System Microfabrication Laboratory which was activated in the summer of 1994. The awarded equipment has strongly impacted the primary research described in the original proposal on advanced interconnection technologies for MCM based systems enabling strides in polymeric optical interconnection work as well as submission of a new proposal in cryosystems and interconnect drawing upon the lab's new prototyping capabilities. Moreover, an unanticipated positive impact of the equipment award has been its role in attracting a new aggressive tenure track faculty member and in coalescing a group of interdisciplinary researchers across WVU whose research can now be linked and expanded through the availablity of a common microfabrication lab resource.